ACOUSTIC CHARACTERISTICS OF CROATIAN CARDINAL VOWEL FORMANTS (F1, F2 AND F3)

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Abstract: In the forensic context formant values (F1, F2 and F3) are measured in speech. Previous Croatian research measured formants in nonsense words or in several phonemes; therefore the aim of this paper was to determine standard values for General Croatian Pronunciation for male and female speakers in words. Pharyngeal resonance and resonance in the back part of oral cavity is the most important for F1 values and the highest F1 value was found for vowel [a]; the front/back position of vowel influences F2 values; the most fronted vowel in Croatian is [i] and it has the highest average F2 value. Due to the contractions in those areas vowel [i] has the lowest values while the most resonant vowel [a] has the highest values. F3 values are important for comparisons of various vowel pronunciations since F3 does not distort in telephone transmission or shows fewer distortions than F1 for most vowels.

Keywords: vowels, formant values, Croatian Received Pronunciation

1. INTRODUCTION

1.1. Articulation – vowel space described by IPA and the description of standard Croatian cardinal vowels

International Phonetic Association illustrates vowel space in a diagram shaped like a trapezium. The horizontal axis from left to right shows front vowels /i/, followed by mid vowels and back vowels /u/ placed on the right (IPA, 1999, 2009). Vertical axis indicates open/close vowel articulation therefore on the top is close vowel /i/ followed by close-mid /e/, open-mid and open /a/ (Figure 1: IPA vowel space). Towards the horizontal axis vowels are placed on each level regarding to the central articulation and on the right regarding to the back articulation. Following that principle, the articulation of standard Croatian vowels is described in General Croatian Pronunciation. Croatian vowel placement is similar to cardinal vowels therefore are sometimes even called cardinal (i.e. Varošanec-Škarić, 2010), although cardinal vowels are not part of phonological inventory of a particular language. It can be noted that symbols in vowel space are paired and only [æ],[ɐ],[ə] and [ʊ] are individual. In the cases of paired IPA vowel symbols, the right symbol stands for rounded, labialized vowel, for example vowels /o/ and /u/ in General Croatian Pronunciation. Such placement and pairing system is practical because vowel symbols for vowel pronunciation in Croatian dialects are easily determined and thus having practical implication for speaker description in real forensic cases.

Therefore, this is a practical choice suitable for comparison. For the description of the General Croatian vowel system we use the term cardinal vowels since phonetic science uses the same term for vowel system consisting of five basic vowels. Furthermore, it has to be emphasized that the following handbooks say that the vowels cannot be described according to the degrees of backness. This is important not to change articulatory descriptions of the standard pronunciation because of the particular research using certain method every time when a particular result is interpreted without being compared to the acoustic measurements. On the other hand, certain idiosyncratic pronunciation cannot be considered for a description of Standard Croatian Cardinal Vowel system. This means that the vowel [u] is described only as back, close and rounded. It is not stated that the articulation of [u] is more back than for [o], which is not logical considering that the degree of backness is not taken into account. In the

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Cardinal System it is neither very rounded nor close. More rounded and more close than [u] is vowel [ʊ] spoken in the dialect variety found, for example, in the wider Varaždin area. It should also be noted that lax/tense articulation influences both perceptual and acoustic characteristics of vowels.

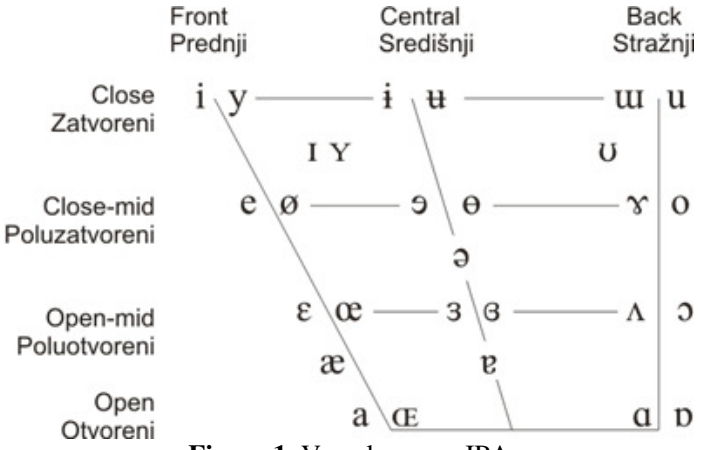

Figure 1. Vowel space - IPA

Vowel [o] is described in General Croatian Pronunciation as close-mid, back and rounded which is also basic cardinal pronunciation. Therefore, the vowel [o] in the General Croatian Pronunciation is not pronounced as extremely back but simply back. Articulation is more closed for long /o/ in southern Croatian varieties (Dubrovnik, Konavle, wider Makarska area), while extremely close articulation of vowels /e/ as [ɛ] and closed /u/ implies origin from Bosnia and Herzegovina. The difference between Kaikavian closed [ʊ] and /u/ in Bosnian and Herzegovinian variety is in tenseness, the latter being more tense.

General Croatian pronunciation of [i] is front, close and tense. It is neither too close nor to tense but it is not lax either. Čakavian dialect variety includes short vowels which can be lax /i/ and /u/ (Škarić, 2009) and also in Kaikavian dialect variety (Varošanec-Škarić and Kišiček, 2009). For those dialect varieties of vowels /i/ and /u/ the used symbols are [ɪ] and [ʊ].

Vowel /e/ is described as mid-close and front.

Ceneral Croatian pronunciation of the vowel /a/ is central regarding the front-back axis. It neither too open nor to close. Vowel /a/ is highly distinctive dialectal feature ranging from [o], or Štokavian, back, darker [ɒ] for long vowels in Dubrovnik area (especially in Konavle) and this are also possible in certain parts of Slavonia. In post-stressed positions the vowel may be reduced and /a/ is pronounced as [ɐ] in Eastern Slavonia. The realization of /a/ as a neutral vowel [ə] is also possible in all positions in Zagreb variety of Kaikavian dialect. In other Kaikavian dialects (Međimurje and Zagorje) vowel /a/ is articulated as [ɔ] in the final spoken word position (see Varošanec-Škarić, 2010: 151). The differences between standard pronunciation are perceived as non-standard: dialect variations such as vowel reductions, reduction of unstressed vowel and diphthongization (change in vowel quality during realization of the stressed vowel) are perceived as non-urban varieties. This is not only impressionistic and indexical perception but current state in the urban Croatian varieties (such as Zagreb, Osijek, Pula, Split and Rijeka. Urban varieties do not include such vowel pronunciation. It is also an important social index and sociophonetic research indicates that educated speakers of urban varieties are assessed as more prestigious (Varošanec-Škarić and Kišiček 2009)

Recent research using different research methods suggest that the descriptions of vowel articulation in Croatian could be changed (for an example Carović, 2014). Carović (2014) used ultrasound to measure vowel articulation and coarticulation in Croatian and revealed certain interesting findings; for an example – vowel /u/ is not the most back vowel. It is more fronted in than /o/ and /a/. It was mentioned before that the degree of backness is not described and that [u] is not pronounced more back than [o] (Škarić, 2009; Varošanec-Škarić 2010: 150). It should be noted that small idiosyncratic tongue placements should not imply differently i.e. that [u] is more fronted than [o] and [a]; at least not when cardinal system is being described. Certainly, certain type of measurement cannot change descriptions of articulation of General Croatian Pronunciation but research with a particular method, in this case tongue movement recorded by ultrasound should be

compared to acoustic measurements. On the other hand, each method shows certain variable, for an example direction of tongue movement, temporal elements etc.

Therefore, the main aim of this research was to use contemporary research methods to determine formant values of Croatian cardinal vowels. It is known that formants are spectral peaks resulting from resonance in the supraglotic cavities (ever since Fant, 1970).

Secondly, pragmatic aim of the research is to determine reference values of vowel formants which is important for description of any language, so that it can be compared to dialect realizations and idiosyncratic pronunciation.

1.2. Previous research of vowel formants

There are three previous researches about acoustic feaures of vowel formants in Croatian. Škarić (1991: 186) mentions results for the first three formants for Croatian vowels based on results obtained from one male speaker in pronunciation of vowels in isolation. Bakran and Stamenković (1990) give results for 17 adult males and 7 female speakers in nonsense words: /pip/,/pep/, /pap/, /pop/, /pup/. The results are later shown in the book Acoustic image of Croatian (Zvučna slika hrvatskoga govora) (Bakran, 1996). Varošanec-Škarić (2010) compared vowel formants in educated opera singers in speech and singing (the materials included anthem, scale and vowel pronunciation X3) (6 M, 7 F). Due to the required control, complexity of the measurements, methodological limitations, number of participants, differences in phonetic context both on segmental and suprasegmental level, choice of words and nonsense words, necessary verification of speakers' pronuniciation researchers cannot take all the variables into consideration at the same time. Therefore for the description of pronunciation the starting point should be traditional description of Croatian vowels and comparison to the acoustic data collected in controlled conditions certain conclusions could be made. The raised questions only contribute to better connections of perceptual assessment with other measurements.

Although the description of standard Croatian vowels regarding the procedures that were used for the description of vowels in Croatian and gave certain conclusions on one hand and phonetic context in the material on the other hand are not always similar and completely accepted, phoneticiam must take into account what is being compared in certain interpretation, the synergy of the procedures and methods during articulatory and acoustic analysis. Forensic phonetics uses comparison of the recordings collected by the police with certain transmittion features. It is clear that the phonetician receives the sample which is always connected speech. Therefore the samples used for comparison with official recordings during verification procedure should be spoken. This also emphasizes the need to measure acoustic characteristics of vowel formants of stressed vowels in words with different phonetic contexts. Recent studies in forensic phonetics discussed formant analysis but some authors such as Nolan (1993, 2007), Nolan and Grigoras (2005), state that sice formant values indicate interaction between three possible identification sources: linguistic accent, anatomy of vocal tract and articulation they should be used. It was noted on several occasions that the analysis of formant values must include limitations depending on type of transmission: telephone or GSM or other recording system. McDougal and Nolan (2007) point that F1 and F2 values imply the dynamics of formant change and that they are speakers' signature. This type of analysis can, for example, determine the difference between monophtongized and diphthongized vowel system among speakers. This can be useful for analysis of vowel systems different from standard since certain dialect varieties include diphtongized pronunciation of monophtongs in standard varieties. It is quite useful tho have the average formant values for all vowels available, especially F1, F2 and F3 measured in controlled conditions in various phonetic contexts. The importance of other data is not opposed, especially when the data include various phonation types of different speakers. Such comparisons reveal that the differences in average vowel formant values (F1 and F2) and voice formants (partly F3 and definitely F4). Therefore experiments must result from real cases to make the comparison possible and interpretation satisfactory.

2. PROCEDURE OF AVERAGE FORMANT FREQUENCY MEASURMENTS FOR CROATIAN VOWEL FORMANTS

2.1. Description of words used for acoustic analysis

Ten words in different phonetic contexts were chosen for each vowel. Target vowel was stressed and the material included all four accents in General Croatian Pronunciation. Regarding phonetic context, the selected material included all vowels surrounded by voiced and voiceless consonants: stops, fricatives, affricates, approximants and sonants. All the speakers assessed as the speakers of General Croatian Pronunciation were included in the study even if they did not pronounced the two short accents (rising and falling) differently. Two-syllable words with stressed first syllable (typical trochaic pattern) appeared on a computer screen and the speakers should pronounce them in a carrier sentence: It is a … [patka]. it should be noted that the formant values can differ depending on the intonation pattern; the difference between rising and falling intonation would influence not only the F0 values, which is logical and expected, but also vowel formant values. Therefore formant values should first be measured in sentences with falling intonation and later should be tested weather they change depending on the intonation for an example how does rising intonation influence vowel formant values.

The chosen words for vowel [a] were: /patka/, /mati/, /faktor/, /tako/, /dabar/, /žaba/, /vata/, /lakat/, /džabe/, /gadno/.

The chosen words for vowel [e] were:: /pekar/, metar/, /leti/, /neto/, /deka/, /šetnja/, /redom/, /četa/, /sedmi/, /keper/.

The chosen words for vowel [i] were: /pita/, /vika/, /rikne/, /bitno/, /čipka/, /nikad/, /sito/, /tigar/, /dika/, /šiba/.

The chosen words for vowel [o] were:: /poklon/, /kopar/, /noga/, /fokus/, /soba/, /šogor/, /roba/, /voda/, /joga/, /čopor/.

The chosen words for vowel [u] were: /buka/, /tupo/, /kupka/, /šupa/, /zubni/, /sutra/, /čudo/, /ruka/, /jutro/, /luka/.

The Tables 1a and 1b in the results section show average values of formant frequencies for F1, F2 and F3 (M), standard deviation (S.D.), and minimum and maximum frequency values (Hz)

2.2. Speakers

The project *Forensic phonetics: standardization of sound procedures*[8] included measurement of of average frequency values, frequency ranges and standard deviations for F1, F2 and F3 for five Croatian vowels in different phonetic contexts for both male speakers (N=14) and female speakers (N=14). Mean age of male speakers is 33, ranging from 22 to 49 and mean age for female speakers was 30, ranging from 22 to 56. The selection criteria were that both experts assessed the speakers' voices as normal (healthy, without voice disorders, neither too high nor too low, without speech and hearing disorders). It is important that the selected speakers spoke General Croatian Pronunciation because standard pronunciation includes articulatory placement only for standard vowels , therefore vowel frequencies cannot be influenced by regional varieties or dialects which could influence supralaryngeal placements.

2.3. Hypotheses

Acoustic theory of F1 and F2 values is based on numerous phonetic researches. The following statements are almost axiomatic:

1. F1 is influenced by open/close vowel articulation: open vowels have higher F1 values and close vowels have lower values
2. F2 is influenced by front/back vowel articulation
3. F1 values are influenced by resonance in pharyngeal cavity and back part of oral cavity
4. F2 values are influenced by front part of oral cavity and the area surrounding tip of the tongue
5. The differences between formant frequencies for various vowels are smaller for men than for women; the difference is based on overall length of the articulatory tract therefore women generally have greater frequency distance between formants and higher average formant values

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It is hypothesized that this research will support the stated hypotheses i.e. that vowel formant values will confirm that the placement of vowels in General Croatian Pronunciation is similar to cardinal vowels' placement.

3. RESULTS AND DISCUSSION

The results of this research are shown in tables. Tables 1a and 1b show formant values (F1, F2 and F3) for male and female speakers. Vowel formant space defined by F1 and F2 values are shown in (Figure 2) for both male and female speakers as well as the distances between the three vowel formants (Figure 3 and 4).

Table 1a. Average frequency values (M) for vowel formants F1, F2 and F3, standard deviation (S.D.), minimum and maximum values – male speakers.

	Hz	**F1**	**F2**	**F3**
[a]	M	707	1221	2417
	min.	518	1015	2009
	max.	826	1548	2691
	S.D.	53.73	104.6	152.83
[e]	M	494	1811	2427
	min.	335	1559	2007
	max.	661	2132	2741
	S.D.	64.47	114.8	146.2
[i]	M	295	2177	2725
	min.	225	1902	2266
	max.	382	2564	3152
	S.D.	30.19	130.72	211.97
[o]	M	511	1069	2405
	min.	366	806	2004
	max.	694	1415	2894
	S.D.	63.19	135.08	194.99
[u]	M	344	799	2410
	min.	218	562	2102
	max.	566	998	2715
	S.D.	59.44	102.63	145.21

Table 1b. Average frequency values (M) for vowel formants F1, F2 and F3, standard deviation (S.D.), minimum and maximum values – female speakers.

	Hz	**F1**	**F2**	**F3**
[a]	M	835	1395	2449
	min.	693	1188	2118
	max.	988	1648	2757
	S.D.	62.76	100.22	133.36
[e]	M	577	2112	2704
	min.	452	1741	2410
	max.	769	2362	2946
	S.D.	64.51	117.72	127.81
[i]	M	370	2375	2832
	min.	310	2049	2338
	max.	498	2679	3182
	S.D.	35.51	125.81	183.5
[o]	M	580	1151	2499
	min.	461	889	2117
	max.	697	1478	2745
	S.D.	55.39	133.51	124.96
[u]	M	403	907	2567
	min.	302	623	2209
	max.	665	1192	2793
	S.D.	54.46	139.4	155.75

Average formant values for formants F1 and F2 can be shown in vowel formant space for male and female speakers.

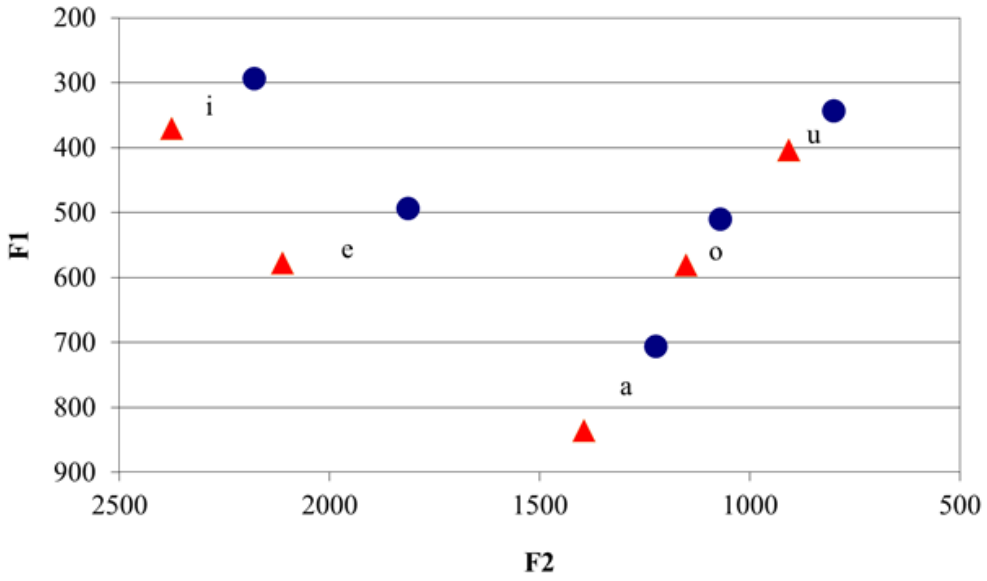

Figure 2: Vowel space defined by values of F1 and F2 for male speakers (●) and female speakers (▲)

The expressed hypotheses and formant definition indicate that conclusion about certain formant frequency cannot be jumped ahead taking into account only one dimension of articulatory placement. Formant frequencies are result of complex phonetic activity. If the results shown in Table1a and Table 1b and Figure2 are compared to the hypotheses it can be concluded that:

1. F1: the highest F1 values are found for vowel [a] for female speakers (835 Hz) and for male speakers (707 Hz), followed by F1 values for [o] for female speakers (580 Hz) and for male speakers (511 Hz). Approximately similar values were found for vowel [e] for female speakers (577 Hz) and for male speakers (494Hz). Formant values decrease for vowel [u] for female speakers (403 Hz) and for male speakers (344 Hz), F1 values are the lowest for [i] for male speakers (295 Hz) and female speakers (370 Hz). Therefore, it can be concluded that the vowel [a] is the most open vowel in General Croatian Pronunciation and vowel [i] the highest / the closest vowel.

F1 is influenced by open/close vowel articulation.

2. F2 is influenced by front / back vowel articulation: front vowels have higher F2 values and back vowels lower. The second hypothesis is confirmed - vowel [i] has the highest F2 values in Croatian due to the front articulation. Average value for female speakers is 2375 Hz (ranging from 2049 to 2679 Hz), and for male speakers 2177 (ranging from 1902 to 2564 Hz). Lower values are found for [e], for female speakers the average value is 2112 Hz (ranging from 1741 to 2362), and for male speakers 1811 Hz (ranging from 1559 to 2132 Hz). It can be noted that the front articulation of the vowels in not only determined by tongue position but also upward larynx movements from neutral position. As expected, F2 values for [a] are about 1000 Hz lower than for [i], the difference is smaller for male speakers which is also expected. The average value for [a] for female speakers is 1395 Hz (ranging from 1188 to 1648 Hz), and for male 1221 Hz (ranging from 1015 to 1548 Hz). It is common that vowel [a] is described as central regarding the front/back axis. It is definitely closest to neutral position of the tongue mass meaning that the center of the tongue mass does not move forward or backward in General Croatian Pronunciation. It is definitely the closest to the neutral position of the vowel [ə], without pharyngeal contractions (no contractions in oropharynx) oral cavity is slightly more open than for other vowels. It should also be noted that front / back placement is influenced by jaw placement but the other articulatory factors also have to be included. Back vowels are not described by different degree of backness so we can say that they only follow the lower average F2 values for vowels [o] and [u]. Average F2 values for vowel [o] for female speakers is 1151 Hz (ranging from 889 to 1478 Hz), and for male speakers 1069 Hz (ranging from 806 to 1415 Hz). Lower average F2 are found for vowel [u], which is for female speakers 907 Hz (ranging from 603 to 1192 Hz), and for male speakers 799 Hz (ranging from 562 to 998 Hz). The results confirm that front / back

articulation influences F2 values and that front vowels have higher average F2 values and back vowels lower.

3. It is confirmed that for F1 values the resonance in pharyngeal cavity is important as well as the resonance in back part of oral cavity meaning that pharynx and back part of oral cavity (oropharynx) are being contracted resulting in lower F1 values. Lower resonance in those parts means that the lowest F1 values will be found for [i] because the contractions are the greatest during articulation and in General Croatian Pronunciation of vowel [a] it is pronounced with open pharynx and wider back part of oral cavity. It is confirmed that the lowest F1 values are found for [i], and the highest for [a] in General Croatian Pronunciation.

Due to higher pharyngeal and oral resonance vowel [a] is always used in phonetic speech exercises at the beginning in order to achieve longer phonation time and smaller shorter coefficient of openness in relation to the entire cycle (Varošanec-Škarić, 2010: 67).

4. The highest F2 frequency is found for front vowels which is cardinal vowel [i] in Standard Croatian. This type of pronunciation gives expected average values for male and female speakers: about 2100 and 2300 Hz respectively. The results show the average value for male speakers is 2177 Hz, and for female 2375 Hz. Therefore, in standard articulation of vowel [i] the center of the tongue mass is placed frontally as well as the tongue tip. It means that the standard pronunciation of vowel [i] must not be rounded (as in some Kaikavian non-urban varieties) because it will lower the F2 values, but also it must not be dentalized (completely closed jaw as in some Bosnian varieties or in varieties from Posavina) because F2 values will be higher than in standard Croatian. Considering everything said for F2 it can be concluded that resonance in front part of oral cavity is important for vowel [i], as well as front tongue tip area, no nasal resonance should be present since lowering of velum lowers F2 values in comparison to standard values. It is logical that standard pronunciation of vowels [o], [u] with tongue mass being slightly back and lips are rounded F2 are lower than for standard [i], which was confirmed by our measurement.

5. Regarding formant vowel space which is based on F1 and F2 values this research confirms that the differences in frequencies between those two formants for all vowels are smaller for male speakers than for female speakers. It is evident that gender differences are smaller for [o] and [u], and the same pattern can be seen in comparison of F2 and F3 values (Figure 3).

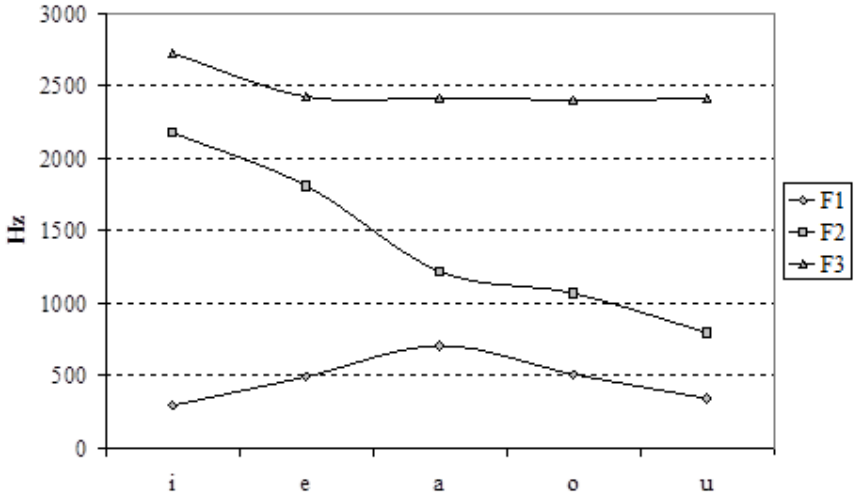

Figure 3: F1, F2 and F3 frequency-ratio for male speakers in General Croatian Pronunciation

The following statement does not refer to the comparison of F2 and F3 for other vowels since the differences are stronger in male speakers – about 100 Hz for [a] and [i]. Although the emphasis is on vowel formants, other formant values must be mentioned. F3 values are significant for forensic phonetics since neither it is distorted as F4 nor as F1 for most vowels. Those formants are least distorted for vowel [a], since F1 for /a/ values are often higher than the telephone transmission band. However there are certain cases when F1 is significantly lower than average and in those cases it can be distorted. This happens mostly for male speakers.

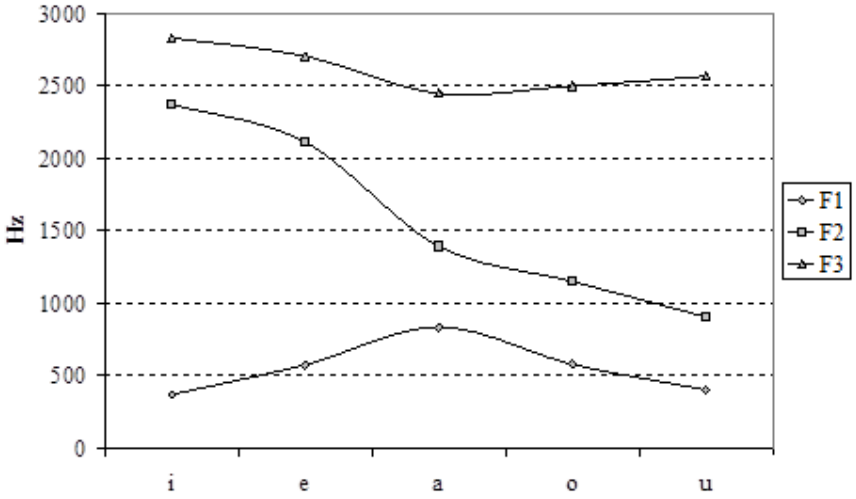

Figure 4: F1, F2 and F3 frequency-ratio for female speakers in General Croatian Pronunciation

Even being less informative, this experiment has confirmed that average formant values for F1 and F2 are lower for male speakers for all vowels. This also applies to F3 since it is also vowel formant and is influenced not only by the length of vocal tract but also by the vowel articulation. It should not be forgotten the differences in articulatory cavities also influence the differences between men and women. What is new is that the greatest average difference in F3 among male and female speakers is found for vowel [e], although the highest frequency F3 was found for vowel [i] for both female and male speakers. Therefore we can conclude that the shortest articulatory tract is for articulation of vowel [i].

4. CONCLUSION

1. The highest average F1 values are found for vowel [a] for both female speakers (835 Hz) and for male speakers (707 Hz) being the most open vowel in Croatian cardinal system. Further, F1 values are followed by the average values for vowel [o] for both female (580 Hz) and male speakers (511 Hz), and almost similar average values for vowel [e]. F1 values decrease further for vowel [u] for both genders while being the lowest for vowel [i] for male speakers (295 Hz) and female speakers (370 Hz). Therefore, it can be concluded that the vowel [a] is the most open vowel in General Croatian Pronunciation and vowel [i] the highest cardinal vowel.

2. It is confirmed that front vowels have higher F2 values while back vowels have lower; vowel [i] has the highest average F2 value in Croatian due to front articulation. Average value for female speakers is 2375 Hz and for male speakers 2177. The results for [i] are followed by F2 values for vowel [e], for female speakers the average value is 2112 Hz and for male speakers 1811 Hz. Average F2 values for [a] for female speakers is 1395 Hz and for male 1221 Hz confirming its cardinal articulation since it is common that vowel [a] is described as central regarding the front/back axis. Vowels [o] and [u] respectively have lower F2 values.

3. The resonance in pharyngeal cavity and back part of oral cavity is important for F1 values and these results support that meaning that contractions in the pharyngeal area and in the back part of oral cavity (the area of oropharynx) cause lower F1 values. The lowest F1 values are found for the vowel [i] because of the greatest degree of constriction, while during articulation of the vowel [a] there is no constriction in that part of vocal tract. This confirms the finding of the lowest F1 values for [i] and the highest for [a] in General Croatian Pronunciation.

4. The highest F2 frequency values are found for front vowels, being cardinal vowel [i] in Standard Croatian. The average values for male and female speakers are about 2100 and 2300 Hz respectively. The results show the average value for male speakers is 2177 Hz and 2375 Hz for females.

5. This experiment has confirmed that the frequency distance between F1 and F2 (vowel space) is lower for male speakers for all vowels. Male and female vowel space differs less for vowels [o] and [u] and the same applies to the frequency distance between F2 and F3.

It is also informative that the greatest average difference in F3 between male and female speakers is found for vowel [e], although the highest F3frequency was found for vowel [i] for both female and male speakers. The results of this research of the acoustic features of Croatian cardinal vowels can be compared to the results of various vowel researches – in Croatian dialects, regional pronunciation, local varieties, and urban varieties but can also be compared to other languages. Furthermore, they can be useful in forensic context, especially when two types of recordings are available – forensic recordings collected during investigation with studio recordings of the suspect's spontaneous utterances during an interview with a phonetician.

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